# Chapter 3
# METHODS

## LAKE OKEECHOBEE

Minimum water level criteria for Lake Okeechobee were based on three sources of information: review of the District's current drought management and water supply plans for Lake Okeechobee, results from recent ecological research on Lake Okeechobee, and the relationship between lake stage and navigation and recreational use of the lake.

### Review of Drought Management Plans

The amount of rainfall that falls in South Florida from year-to-year is highly variable and, in some years, can result in drought conditions. Historical records show that when lake levels fall below 11 ft NGVD, severe water shortage restrictions occur along Florida’s lower east coast. Once below 11 ft NGVD, these levels decline rapidly, affecting the District’s ability to deliver water to downstream users, as well as affecting the ecology of the lake. As water levels drop below 10.5 ft NGVD, structural limitations of the lake’s outlet structures makes it increasingly difficult to withdraw water from the lake to send downstream to protect lower east coast wellfields against saltwater intrusion. In 1982, the District adopted a water management strategy designed to avoid extreme drawdowns of the lake that impact South Florida’s backup water supply. This plan provides a balanced water allocation strategy for all users to avoid severe drawdowns of the lake, a method for holding water in reserve for later high demand periods, and a defined minimum level for holding water in reserve to protect coastal wellfields from the threat of saltwater intrusion. District staff reviewed the *Staff Manual for the Management of Water Shortages* (SFWMD, 1987) and the *Supply-Side Management Plan for Lake Okeechobee* (Hall, 1991) to identify how water is currently managed in the system to ensure that adequate water is stored in the lake to prevent significant harm to the water resources of Lake Okeechobee and the Biscayne aquifer (See **Figure 15** in Chapter 4).

### Ecological Research

#### Minimum Level

Minimum water level criteria were developed to prevent significant harm to the following:

- The lake’s commercial and recreational fishery
- The nesting and foraging habitat of wading birds, migratory water fowl, and the federally-designated endangered snail kite
- Ecotourism, including bird watching, hiking, and other related activities

Significant harm, from an ecological perspective, is considered to be an adverse change in one or more of these values that takes multiple years to recover under normal rainfall conditions. The ecological criteria proposed here are consistent with a conceptual ecosystem model developed by a multiagency panel of experts (Havens and Rosen, 1997), and with the low lake level criterion developed as part of the C&SF Project Comprehensive Review Study (Restudy). The recommendations made in the Restudy are being implemented in the Comprehensive Everglades Restoration Plan (CERP).

The focus of this section is on Lake Okeechobee's littoral zone, the geographic region that provides the ecological values listed above. Quantitative relationships between the values and low lake levels were determined from the following:

- Information regarding fish and wildlife use of different regions of the lake's littoral zone
- Output from a GIS model regarding flooding and drying of the littoral zone as a function of lake surface elevation
- Direct observations of changes that have occurred in the littoral community during and after major drought events
- Results of experimental and observational research relating plant growth rates to water levels

The spike rush (*Eleocharis*) community of Moonshine Bay and the bulrush (*Scirpus*) community at the littoral fringe are particularly important as habitats for wildlife populations (including largemouth bass, black crappie, and the federally-designated endangered snail kite), and as such were considered to be most intimately linked to the lake's ecological and societal values. Review of GIS maps developed as part of this study indicated the critical level at which these habitats are no longer submerged (11 ft NGVD). A matrix of the various aspects of significant harm that have been observed under such low lake conditions was compiled (**Table F-1,** Appendix F). Finally, experimental and observational results regarding the expansion of exotic and nuisance plants (e.g., torpedo grass, melaleuca, and cattail) under various water level regimes were considered, to predict how much their spread would be accelerated under low lake level conditions.

Lake Okeechobee has experienced seven low lake stage events (< 11 ft NGVD) since the lake was encircled by a dike, regulated according to a flood-control schedule, and utilized as a source of water for regional water supply needs. The cumulative impact of these low water events is uncertain, owing to a lack of long-term ecological monitoring of the ecosystem. There is evidence from a littoral plant survey in the 1970s (Pesnell and Brown, 1973) that a diverse wetland plant community persisted in the littoral zone following three droughts during the preceding 20 years when the lake reached 10.1 ft NGVD in 1956, 10.2 ft NGVD in 1962, and 10.3 ft NGVD in 1971. However, impacts of these events on fish and wildlife are not well documented.

In contrast, today's littoral zone has a dramatically different vegetation community, including thousands of acres of the exotic plants melaleuca (*Melaleuca quinquenervia*) and torpedograss (*Panicum repens*). These plants offer relatively poor habitat for fish and wildlife due to their dense growth form, and in the case of torpedograss, the presence of low levels of oxygen within the water column. Results of both observational and experimental research indicate that their expansion into native plant communities may be facilitated by low lake stages (less than 11 ft. NGVD) which dry out the marsh.

Field surveys and GIS maps indicate that torpedograss presently is restricted to more upland areas of the littoral zone, at elevations greater than 13 ft NGVD. However, during a brief period of reduced water levels in 1997, torpedograss expanded into lower elevations of the marsh (Moonshine Bay area) previously dominated by spike rush. Small colonies of torpedograss now occur throughout much of this area. Moonshine Bay is a pristine central region of the littoral zone that provides nesting habitat for game fish (including the largemouth bass), and foraging habitat for wading birds, migratory waterfowl, and the federally-endangered Everglades snail kite (Bennetts and Kitchens, 1997).

Researchers have speculated that if Moonshine Bay should become dry (lake stages less than 11 ft NGVD for an extended period of time), these conditions will allow for the rapid expansion of torpedograss throughout the area. Experimental research conducted by the US Army Corps of Engineers Waterways Experiment Station (Lewisville, Texas) has now confirmed this view. Torpedograss spreads primarily by fragmentation. Small pieces of existing plants are carried to new locations by water currents, and when they become rooted, new colonies form. In controlled experiments, the following was documented:

- Torpedograss fragments cannot successfully become rooted unless they make contact with the sediments
- Fragments generally will not sink to the sediments when there is standing water because they are highly buoyant
- Fragments that are placed in contact with sediments can develop roots, but they cannot successfully produce aboveground leaves and shoots when water depths are greater than 25 cm
- At water depths less than 25 cm, rooting and production of lateral rhizomes occurs quickly (in less than a month)
- Once these plants become established, they can tolerate higher water levels (up to 100 cm) by drawing on reserve energy and nutrients contained in their roots

The relevance of these research results for Lake Okeechobee are (a) torpedograss is unlikely to spread into regions of the littoral zone where water depths exceed 25 cm, (b) in Moonshine Bay, average depths within the bay are below 25 cm when lake stage falls to 11 ft NGVD, and (c) when lake stages fall from 12 to 11 ft NGVD, another critical habitat, the nearshore bulrush (*Scirpus californicus*) community, becomes exposed. The bulrush represents a prime habitat for sportfish nesting and foraging along the lake's western shoreline.

To prevent significant ecological harm from occurring to littoral zone and nearshore communities, it is recommended that lake levels not drop below 11 ft NGVD for extended periods of time to prevent further expansion of torpedograss within Lake Okeechobee.

### Minimum Duration and Return Frequency

Recent research results indicate that lake stages below 11 ft NGVD have the potential to increase torpedograss expansion within the littoral zone. Ideally, the minimum level should also include a duration target (number of days the lake can remain below 11 ft NGVD without causing significant harm), and an allowable return frequency (number of years between events). To date, however, our understanding of the ecosystem is not at a level that permits establishment of science-based criteria for these two attributes. Current research efforts are focused on determining ecological risk versus duration of exposure for various littoral zone plant communities. Results of these ongoing research efforts are not currently available. Until more complete ecological information becomes available, District staff used the lake's current historical period of record (1952-1995) to provide an initial nonecological estimate of the number of successive days and number of years between events that lake levels could be allowed to recede below 11 feet NGVD (see **Figure 18**, Chapter 4). These historical data were used because the present littoral zone plant communities, and hence the hydrologic conditions that have preceded formation of these communities, are considered to be acceptable. However, it is recognized that these conditions merely provide a very simplistic “place holder” in this process, to indicate whether future consumptive withdrawals cause more frequent or prolonged lows than occurred in the past.

### Lake Stage for Navigation and Recreational Use

Information used to determine the lower limit at which significant harm occurs to navigation and recreation access to the lake was based on the following information:

- Review of the document, *Central and Southern Florida Project, Water Control Plan for Lake Okeechobee and the Everglades Agricultural Area* (USACE, 1991), which identified the water depths needed for safe navigation of the Okeechobee Waterway
- A bathymetry map of Lake Okeechobee showing one foot contours of the lake bottom (**Figure F-1,** Appendix F)
- Discussions with local marina operators and boat captains who provided insight regarding their navigation experiences on the lake during low lake stages.

## EVERGLADES

Development of minimum water level criteria for the remaining Everglades was based on three primary sources of information: a review of the literature, results obtained from output of the Natural System Model version 4.5 F (NSM v 4.5 Final), and a review of historical water levels and fire records. The processes used to review and integrate this body of information are described below.

## Literature Review

A review of scientific and technical literature was conducted to compile and summarize available information that describes the ranges of water levels that occur during drought conditions within the Everglades and within other peat and marl based wetland systems. The search was limited primarily to include studies conducted within South Florida to document minimum water levels recorded during low rainfall periods and their subsequent impact on wetlands. These data were synthesized into tables to show ranges of minimum water levels, the duration of each event, and return frequency. A computer bibliographic search (Dialog Information Service) was also conducted using the following key words: hydric soils, peat and marls, soil subsidence, Everglades water levels, Everglades hydroperiod, changes in Everglades plant communities, fire in the Everglades, effects of drought in the Everglades, and minimum water levels. Results of this search are included in the list of references provided in **Appendix E** of this report. Technical publications produced by the SFWMD and the South Florida Research Center at Everglades National Park were also reviewed. The final product includes a list of technical publications that discuss low water periods observed in the Everglades as well as documented events where environmental impacts have been documented as a result of overdrainage of the system.

## Review of Historical Water Levels and Fire Records

Fire is a natural force that has shaped the Everglades ecosystem. Periodic fires prevent the natural succession of fire-adapted species such as sawgrass or maidencane to woody or bush vegetation. Communities maintained by fire are called fire subclimax communities. Conversely, severe fires that consume peat and damage wetland plant communities can result in ecological impacts that last from 3 to 10 decades (DeAngelis, 1994). Therefore, a potential increase in the frequency of severe fires, due to lowered water levels or shortened hydroperiods relative to historic conditions, represents an impact to the water resource functions of the Everglades and should be considered when establishing MFLs. In this study, District staff reviewed historical hydrologic conditions at key water management locations located within the WCAs, the Holey Land and Rotenberger WMAs, and within the freshwater regions of Everglades National Park. These data were compared with available fire records provided to the District by the FGFWFC, as well as those obtained from published literature (e.g., Loveless, 1959; Robertson, 1953; Craighead, 1971; Gleason and Stone, 1974; Schortemeyer, 1980; Wade et al., 1980; Taylor, 1981; Zaffke, 1983; Alexander and Crook, 1984; Gunderson and Synder, 1994).

## Modeling

The Natural Systems Model (NSM) has been used as a means to estimate and compare water depths, duration, and return frequencies for low water conditions in the remaining Everglades system under natural conditions. The NSM provides a means to simulate the hydrologic response of the predrainage Everglades, using recent (1965-1996) records of rainfall and other climatic inputs, and determine how the unaltered system would have responded to recent climatic (rainfall) conditions. The NSM was first developed in 1989 by District staff (Perkins and MacVicar, 1991) and has been revised and updated. Version 4.1 of the NSM was adopted by the Scientific Working Group (1995) as the best available tool to simulate the hydrologic response of the natural Everglades. Further refinements have been made to the model and the current release is version 4.5 Final.

Use of the NSM was of limited value in the analysis to determine MFLs for the Everglades, because this system has been extensively modified from its historic condition. The nature and effects of these modifications were described previously in the Water Resources Considerations section of Chapter 2. Although the Everglades cannot be restored to its predrainage condition, other efforts, such as the Comprehensive Everglades Restoration Plan, are underway to determine the best means to achieve as much restoration as possible.

The NSM modeling approach was used help estimate certain aspects of the Everglades MFL criteria because predrainage hydrologic data do not exist for these areas. Use of recent historical rainfall data allows comparisons to be made between the response of the natural system and that of the current managed system under identical climatic conditions. In this sense, the NSM is a useful planning tool to understand how the natural system originally worked and native ecosystems may have responded, without the canals, levees, and water management structures in place.

In the NSM, the canals, structures, and levees are replaced with the rivers, creeks, and channels that discharge water from the interior of the peninsula toward the coast through a simulated version of the transverse glades, which extended along the coast in Broward and Miami-Dade counties. Historical sheetflow characteristics, which were present prior to development of South Florida, are used to convey water through the marshes. The vegetation and topography used by the NSM are based on estimates of predrainage conditions. Historical vegetation is based on a map originally developed by Davis (1943a) and later updated and modified by Costanza (1975). Historical topography is based on current knowledge of ground elevations in the Everglades and is updated using best available historical data (e.g., ground levels recorded during construction of the primary canal system through the Everglades). In areas where the historical topography is higher than current conditions, surface water ponding depths are presented as adjusted, or normalized, to ground level for both the current managed system and the NSM.

In this study, the NSM was used as one of several sources of information that District staff reviewed to examine how low, for how long, and how often water depths declined under natural conditions during low rainfall years. Review of the available literature identified information that could be used to estimate the minimum water depth (how low) and the duration that water levels remained at low levels (how long). The literature however did not provide information of the frequency with which such events could be expected to occur (how often).

For example, descriptions of Everglades National Park, prior to construction of regional drainage facilities, showed that areas such as Shark River Slough were flooded for long periods of time. Occasional regional drought events occurred under natural conditions that lowered water levels in the slough to one foot or more below ground, but there is no direct observational evidence to document how often such events occurred. The NSM provides a means to translate what is known of historical topography, landscape ecology, and rainfall patterns to estimate this frequency. NSM results indicated that some areas in the slough dry out once every 10 to 15 years, while other areas apparently remain permanently flooded or dry out less than once every 30 years.

Under natural conditions in the northern Everglades, portions of the sawgrass plain located south of Lake Okeechobee dried out more frequently and experienced periodic low water levels of a foot or more below ground and occasional fires, perhaps once every 4 to 5 years.

Analyses using the NSM to determine frequency of drought conditions focused on locations that represent present day water management gauges within the WCAs and Everglades National Park. Key gauges selected for this analysis are shown in **Figure 18** (in Chapter 4), and include the following:

- The 1-7 gauge located in the central portion of WCA-1
- The 2A-17 gauge in the central portion of WCA-2A
- The 2B-21 gauge at the south end of WCA-2B
- The 3A-2 (deer gauge), 3A-3, 3A-NE, and 3A-NW gauges in northern WCA-3A
- The 3A-4 and 3A-28 gauges in central and southern WCA-3A
- The 3B-SE gauge in the southeast portion of WCA-3B
- The NP-201, G-620, NESRS-2, NP-33, NP-36, NP-38, G-1502, and NP-67 gauges located in Everglades National Park

# BISCAYNE AQUIFER

Development of minimum water level criteria for the Biscayne aquifer were determined from three primary sources of information: a review of the available literature; a review and evaluation of historical water levels and water quality data from area monitoring wells; and a review of various ground water models to determine the relationships among ground water levels, aquifer characteristics, and the degree of saltwater intrusion that could be expected during a major drought.

## Literature Review

A review of the available literature was conducted to compile and summarize existing information on the hydrology and hydrogeology of southeastern Florida, the Biscayne aquifer, and saltwater intrusion within an unconfined aquifer system. Scientific literature was obtained using an online computer search and manual location of information. This review was generally limited to references specific to southeastern Florida; however, more general literature on the mechanics of saltwater intrusion was also reviewed. A summary of the key information obtained from the review are cited below and are included in the literature cited section of this report. In addition to the literature cited in the text, many other references may be found within the cited works themselves. The primary focus of this review was to understand the mechanics of saltwater intrusion within the Biscayne aquifer and to determine if a scientifically defensible relationship exists among ground water levels, aquifer characteristics, and the degree of saltwater intrusion. In addition to the literature review, water level and water quality data were also analyzed for more than 500 monitoring wells located throughout the study area. Sources of information included U. S. Geological Survey (USGS) data, the SFWMD SALT data base, and various consulting reports and articles.

A thorough description of the stratigraphy and geologic history of the deposits comprising the Biscayne aquifer is provided in Parker et al. (1955) and elaborated on by Hoffmeister (1974) and White (1970). Information concerning the delineation and extent of the Biscayne aquifer is presented in Fish (1988), Klein and Hull (1978), and Shine et al. (1989). These sources base the definition of the Biscayne aquifer on hydraulic properties rather than on geologic formation boundaries.

A number of sources provide information on the lithology and hydraulic characteristics of the Biscayne aquifer, including Fish (1988), Fish and Stewart (1991), Shine et al. (1989), and Restrepo et al. (1922). The bulk of the aquifer material consists of highly permeable, cavity-riddled limestones and sandstones of the Pamlico Sand, Miami Limestone, Anastasia Formation, Key Largo Limestone, Fort Thompson Formation, and part of the Tamiami Formation. Descriptions of these formations are provided by Parker et al. (1955). Hydraulic conductivity of the Biscayne aquifer ranges from 500 to 4,000 feet per day in Palm Beach County (Shine et al., 1989), to more than 10,000 feet per day in Broward and Miami-Dade counties (Restrepo, 1992; Fish, 1988; Fish and Stewart, 1991).

General information on the mechanics of saltwater intrusion was found in Freeze and Cherry (1979), Bear and Todd (1960), and Domenico and Schwartz (1990). These references also describe the Ghyben-Herzberg relationship as discussed in this report. Wirojanagud and Charbeneau (1985) describe the phenomenon of saltwater upconing around pumping wells. The cyclic flow of saltwater in the Biscayne aquifer was discussed in Kohout (1960) and Merritt (1996).

The work of both Kohout (1960) and Merritt (1996) suggest that salt water under tidal influence can move greater distances and be more easily incorporated in seaward discharge of fresh water in heterogeneous aquifers with high hydraulic conductivity, like the Biscayne aquifer, than in less permeable, more lithologically uniform aquifers. Merritt (1996) also points out that when diminished rainfall and lowered ground water stages decrease freshwater inputs to tidal canals, sea water can circulate inland close to the land surface rather than at depth during high tides. Bear and Todd (1960) show that tidal fluctuations cause the transition zone between salt and fresh water to be larger closer to the coast, and suggest that aquifer heterogeneity may also encourage a wider transition zone.

All of these references combine to illustrate the complex interaction between hydraulic properties of the aquifer, tidal action, rainfall and runoff, pumping in coastal wellfields, ground water levels, and coastal stages.

Information on the location of the saltwater interface in the Biscayne aquifer during various years was obtained from reports prepared by J.M. Montgomery, Inc. (1986), Sonenshein and Koszalka (1995), and Merritt (1996). Water level and chloride data from USGS, SFWMD, and consultant reports were analyzed to determine average and seasonal water levels and to help determine the position and movement of the saltwater interface.

Insight into the influence of rainfall on ground water elevations and flow patterns was obtained from Sonenshein (1994) and Merritt (1996), and also through comparison of rainfall and water level data. Merritt (1996) includes a discussion of the effects of water management controls on seasonal average water elevations and on the movement of the saltwater interface in response to short- and long-term low water periods. Merritt concluded that it is average annual or long-term ground water levels, rather than seasonal variations, which significantly affect the position of the saltwater interface.

## Data Analyses and Modeling Approaches

To determine a minimum level that should be established for the Biscayne aquifer, the following four separate approaches were used:

- An evaluation of water quality and water level data from LEC Planning Area monitoring wells and canal stage data from coastal water management structures was performed.
- An evaluation of the influence of the maintained canal levels on coastal aquifer water levels using the South Florida Water Management Model (SFWMM).
- An evaluation of various canal stages and their influence on the position of the saline interface using a two-dimensional solute transport/flow model (SWICHA) was performed (Andersen et al., 1986).
- These data were compared to the well known Ghyben-Hertzberg relationship as a method for determining the minimum level that should be maintained to prevent saltwater intrusion of the Biscayne aquifer. It should be noted that the Ghyben-Hertzberg relationship was not used in the study to establish any minimum level proposed in this report. It is used here for comparison purposes only.

### Evaluation of Monitoring Well Data

Water level and water quality data from 500 monitoring wells within the study area were evaluated. Average dry and wet season water levels were determined for each well. In addition, initial, mean, and final chloride concentrations were noted for each monitoring well to determine if the saltwater front had reached that monitoring well, if the front was stable, if the front was still moving, and long-term trends. The depth of each well was also noted. Stage duration curves were developed for each coastal control structure. The mean and 84th percentile stages were calculated and the data were then analyzed to determine if there was a relationship between water levels and chloride concentration. Analyses of these data found coastal canal stages maintained near the 84th percentile (one deviation from the mean) as the best fit for protecting the aquifer against further saltwater intrusion. Statistical analyses were also completed for 49 selected wells to determine the correlation between well water levels and chloride concentration. Correlation coefficients, covariance, standard deviation, mean, and variance statistics were performed to assist this evaluation.

### SFWMM Modeling

The SFWMD maintains over 1,400 miles of canals, levees, and water management structures designed primarily to provide drainage for developed areas along Florida's lower east coast. This extensive canal system (**Figure 10**) also plays an important role in preventing further inland migration of salt water into the Biscayne aquifer. During times of drought, water is maintained in coastal canals by transporting water from the WCAs or from Lake Okeechobee eastward into coastal basins.

Development of MFLs for the Biscayne aquifer required an understanding of how the canal network influences coastal water level conditions within specific geographic areas. The South Florida Water Management Model (SFWMM) was used to analyze the interaction between the coastal canals and aquifer water levels during times of drought. The SFWMM is a two-dimensional, regional-scale, integrated surface-ground water flow model that simulates the hydrology and water management of southeastern Florida. The model covers an area of approximately 7,600 square miles, and includes the remaining Everglades ecosystem, the urbanized east coast, and agricultural areas located south and east of Lake Okeechobee. The model performs a continuous daily simulation over 31 years (1965-1995) of historical data, including operation of the canal network.

In setting MFLs to prevent saltwater intrusion, it was necessary to evaluate what influence these canals have on water levels within the Biscayne aquifer. To increase the understanding of the relationship between the canal network and aquifer water levels, two separate model runs were simulated using the SFWMM:

- The first simulation consisted of operation of the system under present conditions. That is, coastal canals, which are currently maintained by the regional system during drought periods, continue to receive water from the WCA system and Lake Okeechobee during low rainfall years.
- The second simulation evaluated another option in which coastal canals were not maintained for water supply purposes during drought years.

Each scenario used daily climate data for the period of record (1965-1995). A water shortage trigger module, developed as part of the LEC regional water supply planning process was used to record water levels at key monitoring locations along the

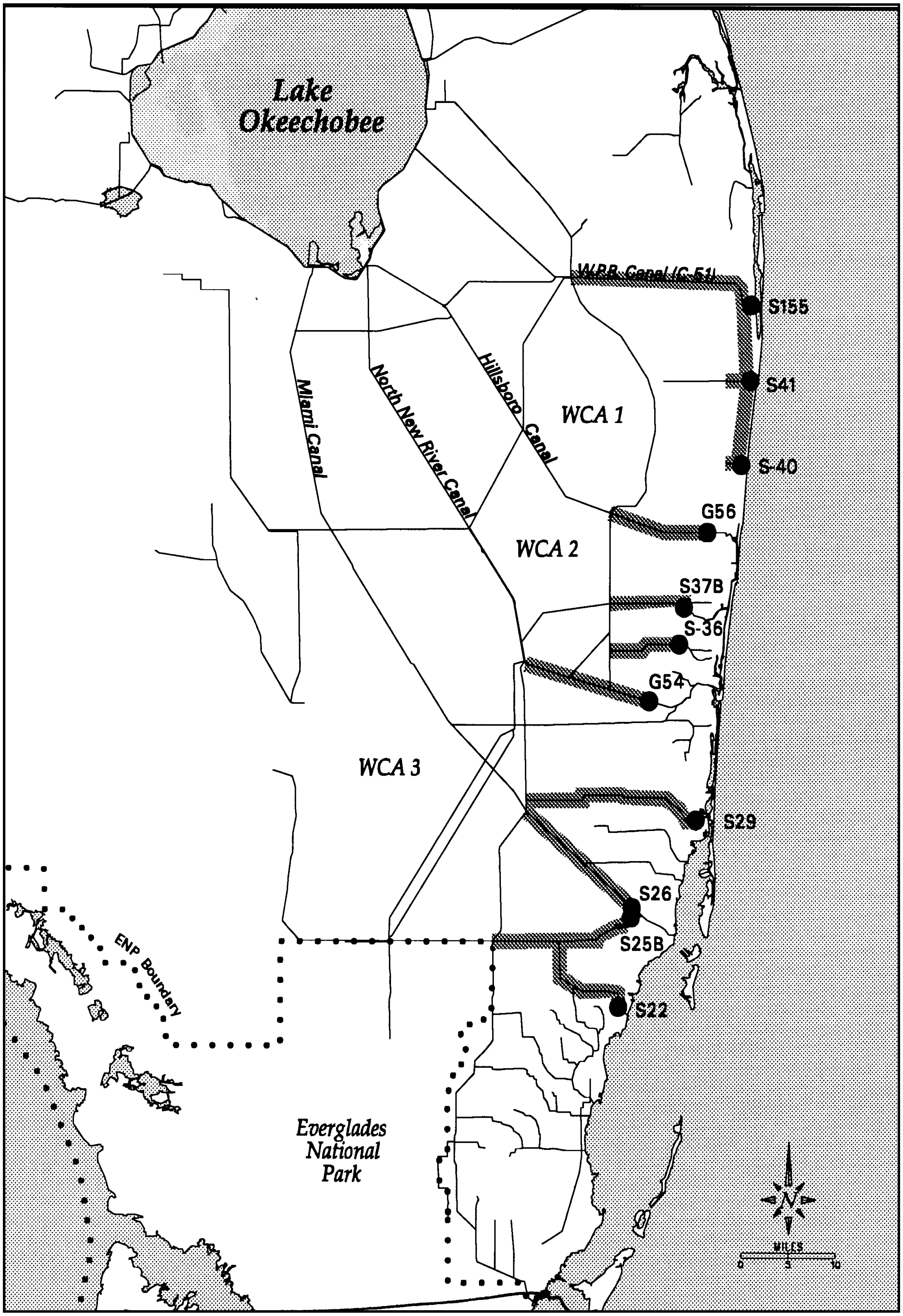


**Figure 10.** SFWMD Coastal Canal Network Indicating Key Water Management Canals and Structures for Maintenance of Minimum Levels in the Biscayne Aquifer.

coast. The water shortage module predicts when water shortage restrictions should be evoked based on water levels near the saltwater interface. In general terms, a Phase 1 water shortage is anticipated when coastal water levels fall below 1 ft NGVD. Data from 20 key monitoring locations were recorded along the lower east coast of Florida. Results of the maintained canal simulation were compared with results of the nonmaintained canal simulation at key monitoring locations to determine the role that the regional canal system played in preventing saltwater intrusion within the Biscayne aquifer.

## Saltwater Intrusion Modeling

Another method used to determine minimum levels for the Biscayne aquifer was to estimate the position of the saltwater interface from the results of various local-scale modeling scenarios. Preliminary results were based upon two-dimensional, cross-sectional modeling of the Biscayne aquifer at various transects along the southeast coast of Florida. Variations of inland water levels and impacts of canal water level changes were analyzed and evaluated. The model used to gain a general understanding of local-scale saltwater intrusion within the Biscayne aquifer was SWICHA, a three-dimensional, finite element code developed by Huyakorn, Mercer, and Andersen (1986) for analyzing seawater intrusion in coastal aquifers. The SWICHA model allows both two-dimensional, cross-sectional analysis of saltwater intrusion and more elaborate three-dimensional evaluations. In this study, five separate two-dimensional cross-sectional models were developed and modified from the work of Andersen et al. (1986) to evaluate various MFL scenarios.

## Evaluation of the Ghyben-Herzberg Relationship

For comparison purposes, the theoretical Ghyben-Herzberg relationship (Todd, 1980) was also evaluated to determine the minimum level that should be maintained to prevent saltwater intrusion of the Biscayne aquifer. **Figure 9** in Chapter 2 shows the idealized Ghyben-Herzberg relationship model for the freshwater/saltwater interface along a coastal aquifer. The Ghyben-Herzberg relationship assumes that the interface exists in a static equilibrium, with a hydrostatic pressure distribution in the freshwater region of the aquifer and stationary salt water (Bear, 1972). The equation developed by Ghyben and Herzberg to simulate their observations is:

$$Z = hf \times 40$$

*where:*
*Z = Depth to saltwater interface (feet below sea level)*
*hf = Freshwater head (ft NGVD)*

In evaluating the applicability of this method to South Florida conditions, several variables are known. These include historical water level and chloride concentrations from a number of monitoring wells along the coast, the depth of each monitoring well, and the depth to the base of the Biscayne aquifer. The theoretical freshwater head necessary to prevent saltwater intrusion is based on calculation of the Ghyben-Herzberg relationship for each selected monitoring well. The depth of the monitoring well was divided by 40 to obtain the theoretical freshwater head as the slope of the saltwater interface is 40 times greater than the slope of the water table. The theoretical freshwater head was then compared to actual wet and dry season average water levels recorded for each well. If the actual recorded water level was greater than the theoretical freshwater head, then it was assumed that saltwater intrusion would not occur. If the value was less than the theoretical head, it was assumed that salt water could potentially contaminate the monitoring well. Average and recent chloride concentration data from each well were then used to determine the percentage of wells that could remain as fresh water producing wells and those that might be affected by salt water, as predicted by the Ghyben-Herzberg relationship.

It should be emphasized here that District staff did not use the Ghyben-Herzberg relationship to establish any minimum level recommended in this report. Its use here is **for comparison purposes only**.